UCLA
UCLA Electronic Theses and Dissertations

Title
Investigation of Glove Permeation of Mixture

Permalink
https://escholarship.org/uc/item/8w90t077

Author
Chen, Yu-Tzu

Publication Date
2018

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA

Los Angeles

Investigation of Glove Permeation of Mixture

A thesis submitted in partial satisfaction

of the requirements for the degree Master of Science

in Environmental Health Sciences

by

Yu-Tzu Chen

2018

ABSTRACT OF THE THESIS

Investigation of Glove Permeation of Mixture

by

Yu-Tzu Chen

Master of Science in Environmental Health Sciences

University of California, Los Angeles, 2018

Professor Shane S. Que Hee, Chair

Mixtures are widely used in both industry and home. Nearly all the technical grade

feedstocks of industry are mixtures. Previous studies have indicated that some chemicals in

mixtures can permeate through glove materials faster than expected from the pure solvent

alone. The hypothesis was that some chemicals in the mixtures will permeate through the

disposable nitrile glove faster in the presence of other chemicals. The aims of the present

research were (1) to determine if a specific disposable nitrile glove was resistant to chemicals

in a mixture, and (2) to determine which chemicals permeated fastest. In the present research,

the mixture of 2-butoxyethanol (2-BE; 29.0%), monoethanolamine (MEA; 9.0%),

polyethylene glycol nonylphenyl ether (PGNE; 2.9%) and water (59.1%) simulating a

common floor stripper used in the workplace was investigated to determine if disposable

Lavender nitrile powder-free exam gloves from Kimberly-Clark were resistant. The

American Society for Testing and Materials Method F739-12[1] for permeation resistance under continuous contact was used, with samples taken at specific times from the collection side of the permeation cell for later analysis by gas chromatography-mass spectrometry. The standardized breakthrough times (SBTs) of 2-BE in the mixture were 0-5 minutes for 2-BE and 5-10 minutes for MEA, compared with 5-10 minutes for 2-BE in water and 10-20 minutes for MEA in water. The steady-state permeation rates (SSPRs) of 2-BE and MEA in the mixture were 85±13 and 35±21 g/cm^2/min, respectively. The SSPR of 2-BE in water was 269±23 g/cm^2/min and the SSPR of MEA in water was 37.5±3.4 g/cm^2/min. Chemicals in mixtures did permeate through glove materials faster than expected in the solvent alone. The Lavender disposable nitrile glove is not recommended to resist this mixture by Kimberly-Clark criteria. Some of the limitations in this study were: (1) PGNE is a polymer and could not be detected by GC-MS, so it is difficult to evaluate the effect of PGNE on permeation. (2) The commercial mixture could not be purchased in a small amount. (3) Hand motions could not be taken into account.

The thesis of Yu-Tzu Chen is approved.

Niklas Krause

Irwin H. Suffet

Shane S. Que Hee, Committee Chair

University of California, Los Angeles

2018

TABLE OF CONTENTS

List of Figures

List of Tables

ACKNOWLEDGEMENTS

1. INTRODUCTION

1.1. Hypothesis and Aims

The hypothesis was that some chemicals in the mixtures will permeate through the disposable nitrile glove faster in the presence of other chemicals. The aims of the present research were (1) to determine if a specific disposable nitrile glove was resistant to chemicals in a mixture, and (2) to determine which chemicals permeated fastest.

1.2. Background

1.2.1. Glove Permeation

Workers who are involved in production and transport of chemicals might be exposed to hazardous chemicals through different routes, including inhalation, ingestion and skin contact. Since engineering controls could not eliminate all the chemical exposures, personal protective equipment (PPE) serves as the last line of protection. PPE includes respirators, goggles, chemical resistant clothing and others; in terms of dermal exposure, a glove is one of the most common PPE. The exposure might cause skin irritation, dermatitis, burns, and even cancer if the glove is not resistant. Thus, the glove permeation resistance was evaluated in this study by the American Society for Testing and Materials (ASTM) F739-12[1] 'Standard

Test Method for Permeation of Liquids and Gases through Protective Clothing Materials under Conditions of Continuous Contact.' The permeation of a chemical through a protective clothing material can be assessed by measuring the standardized breakthrough time (SBT), steady-state permeation rate (SSPR), and cumulative permeation over a period of time.

When a chemical adsorbs onto the contact surface of the glove, it will diffuse through the glove and desorb at the opposite surface of the glove. Fick's First Law can express the diffusion of chemicals through the glove in Equation 1:[5]

$$J=D*A*(dc/dl)…………(1)$$

where J is the permeant mass transfer rate (μg/min);

D is the diffusion coefficient (cm^2/min);

A is the exposed area (cm^2);

c is the permeant concentration (μg/cm^3);

l is the glove thickness (cm).

The diffusion coefficient (D) can be calculated by extrapolating the mass or mass/area versus time permeation steady state region to zero mass at lag time (LT, minute) and using Equation 2:

$$D= l^2/ 6*LT ……………….(2)$$

If significant swelling or shrinking of a material occurs, Equation 2 is not valid.

Additionally, most of the chemical resistance guides and laboratory testing have been carried out to investigate the glove permeation by a single solvent. However, workers will handle mixtures in most of the cases since technical grade solvents in industry are mixtures, and it makes the selection and use of gloves more challenging. There is a need to investigate glove permeation of mixtures. Previous studies have assessed different mixtures, including pesticides, hair dyes and aromatic solvent mixtures[2, 3, 6]. Chao et al.[2] found out that in the BTEX mixture (Benzene, Toluene, Ethyl benzene and *p*-Xylene), the slowly permeating component of a mixture broke through nitrile gloves earlier than its pure form.

1.2.2.   Test Compounds

1.2.2.1. 2-Butoxyethanol (2-BE)

1.2.2.1.1. Physical Properties

CASRN: 111-76-2

Molecular Formula: $C_6H_{14}O_2$

Molecular Weight: 118.2 g/mole

2D-Structure:
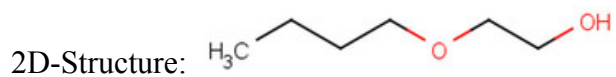
Physical Description: A colorless liquid with a mild ether-like odor.

Density: 0.9015 g/mL at 20℃

Flash Point: 67℃ (closed cup)

Boiling Point: 168.4℃;

Melting Point: -74.8℃

Solubility at 25°C: miscible in water; Soluble in ethyl alcohol, ethyl ether, mineral oil, most

organic solvents.

Vapor Pressure: 0.88 mmHg at 25℃

1.2.2.1.2. Uses and Toxic Effects

2-BE has been widely used in industry. It can be found in paints, surface coatings, inks, hydraulic fluids and cleaning products. In the U.S., 2-BE is produced greater than 100 million pounds per year and considered as a high production volume chemical (i.e. the chemical produced or imported into the United States in quantities of 1 million pounds or 500 tons per year.)[7].

According to the Occupational Safety and Health Administration (OSHA) Hazard Communication Standard (HCS) (29 CFR 1910)[8,9], 2-BE is classified as Category 4 for oral, inhalation, and dermal acute toxicity, Category 2 for skin irritation. Also, 2-BE is a combustible liquid and should be stored in a well-ventilated place.

Industrial exposure to 2-BE is most likely through inhalation and dermal routes during the use of products containing 2-butoxyethanol. 2-BE is metabolized via alcohol and aldehyde dehydrogenases after entering the human body, and form 2-butoxyacetaldehyde and 2-butoxyacetic acid. It is a moderately acute toxin and irritating to the eyes and skin, but not a skin sensitizer. The American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) for worker exposure is 20 ppm[10]. Its biological exposure index (BEI)[10] for 2-BE is 200 mg BAA/g creatinine in a spot urine at the end of shift, with BAA

being butoxyacetic acid (BAA). The carcinogen classification of 2-BE is A3, which is a confirmed animal carcinogen with unknown relevance to humans[10]. The OSHA has a permissible exposure limit (PEL) of 50 ppm (240 mg/m^3)[11]. Harmful health effects have been observed in animals exposed to high levels of 2-BE. For dermal exposure, the LD_{50} of male rabbits is 400 mg/kg[10]. The oral LD_{50} in rats was 470 mg/kg[12].
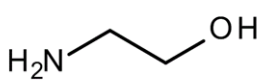
1.2.2.2. Monoethanolamine (MEA)

1.2.2.2.1. Physical Properties

CASRN: 141-43-5

Molecular Formula: C_2H_7NO

Molecular Weight: 61.083 g/mole

2D-Structure:

Physical Description: A colorless and viscous liquid or solid (below 10.56°C) with an unpleasant and ammonia-like odor.

Density: 1.018 g/mL at 20°C

Flash Point: 91°C (closed cup)

Boiling Point: 170.3°C;

Melting Point: 10.4℃

Solubility: Miscible with water ($1*10^6$ mg/L at 25℃), methanol, acetone and ether.

Vapor Pressure: 0.404 mmHg at 25℃

1.2.2.2.2. Uses and Toxic Effects

MEA is used as feedstock in the production of detergents, emulsifiers, polishes, corrosion inhibitors and chemical intermediates. Workers involved in production of MEA or using the products containing MEA may breathe in mists or have direct skin contact. People are also exposed to MEA when using household cleaning products or hair care and coloring products containing MEA. If MEA is released to air, it will be degraded by reactions with other chemicals and light. ACGIH has TLV 8-hr time weighted average (TWA) of 3 ppm and short term exposure limit (STEL) of 6 ppm[10]. The OSHA PEL for MEA is 3 ppm[11]. MEA is also classified as Category 4 for oral, inhalation and dermal acute toxicity in OSHA HCS[13].

MEA is irritating to the skin, eyes, and respiratory tract[14]. Inhalation of MEA by humans was reported to cause immediate allergic responses of dyspnea and asthma and clinical symptoms of acute liver damage and chronic hepatitis[15]. Redness, pain and burns

might occur if there is skin or eye exposure. In rabbits, when exposed to undiluted MEA liquid, it caused redness and swelling of the skin[7]. Administration of MEA by the intravenous route in dogs led to increasing blood pressure, salivation, diuresis and pupillary dilation[16].

1.2.2.3. Polyethylene glycol nonylphenyl ether (PGNE)

1.2.2.3.1. Physical Properties

CASRN: 9016-45-9

Molecular Formula: $(C_2H_4O)Multi-C_{15}H_{24}O$

Molecular Weight: 680.0 g/mole

2D-Structure:
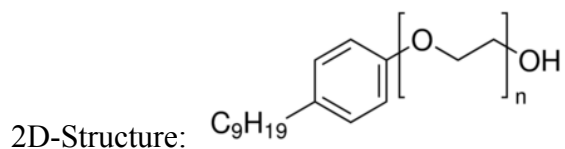
Physical Description: A clear and viscous liquid.

Density: 1.06 g/mL at 20℃

Flash Point: 113℃ (closed cup)

Melting Point: 57-58℃

Solubility: 153 g/L at 25℃

Vapor Pressure: 1.1 mmHg at 25℃

1.2.2.3.2. Uses and Toxic Effects

PGNE had been an ingredient contained in pesticides but it is no longer in use. It can be added in metal cleaners as a dispersing agent, which can lower surface tension and color the water used for flushing. PGNE is also a surfactant[17].

PGNE is corrosive chemical and might cause aquatic toxicity when released to the environment[18]. Exposure to PGNE may occur through inhalation and dermal contact at workplaces where PGNE is produced or used. Exposures are very common, but significant effects are rare and human health data are limited. It might cause local irritation and injury when using detergents. In animal toxicity studies, the rabbit skin LD_{50} is 2000 mg/kg; the rat oral LD_{50} is 1310 mg/kg[12].

1.2.2.4 Mixture

The mixture of interest is a common floor stripper, which contains 20-30% 2-BE, 5-10% MEA, 1-3% PGNE and 60-70% water[19]. The mixture is a colorless to light yellow liquid with a citrus odor. The melting point is 0°C (estimated) and boiling point is 100°C (estimated). The flash point is 93.9°C (estimated). The mixture is stable under normal conditions; however, it reacts violently with strong acids.

The mixture is harmful if swallowed, causing digestive tract burns. It might also cause skin irritation and burns. Thus, it is suggested to use the mixture under good general ventilation (typically 10 air changes per hour) and wear appropriate gloves and safety glasses. Also, the mixture is harmful to aquatic life with long lasting effects[19].

2. EXPERIMENTAL

2.1. *Apparatus*

Lavender Nitrile Powder-Free Exam Gloves were used to study their glove permeation. The weights of each glove specimen were measured by an analytical balance (Mettler AE 260 DeltaRange®) and the thicknesses were measured by a micrometer gauge (Marathon, catalog No. CO 030025).

In the glove permeation test, four permeation test cell chambers (ASTM type I-PTC-600, Pesce Lab Sales, Immersible closed loop chamber) (Figure 1) were used. The chambers were placed into a calibrated shaking-tray constant temperature water bath (Thermo Scientific, Model 2870) at $35.0\pm0.5°C$ operated at 70 revolutions/min. Variable pipets with long tips were used to transfer 0.1-mL samples from the collection side of the permeation cell and 1-mL vials to store 0.1 mL of each sample at 4°C. A 10-μL syringe (Hamilton Company) was used to inject samples into the gas chromatograph-mass spectrometer (GC-MS), an Agilent 6890N-Agilent 5973. The moderately polar HP-5MS capillary column dimensions were 60.0 m*320 μm inner diameter *1.00μm film thickness.

Figure 1. The Test Chambers in the Water Bath

2.2. Chemicals

2-BE (Sigma-Aldrich), MEA (Sigma-Aldrich), PGNE (Sigma-Aldrich), 4-BP (Aldrich), H_2O

(deionized water) and liquid neutral detergent. Helium (99.999% purity) was used as carrier

gas.

2.3. Procedures

The ASTM Standard Test Method F739-12[1] under conditions of continuous contact was

employed to test glove permeation. The permeation was assessed by measuring the

standardized breakthrough time (SBT), steady-state permeation rate (SSPR) and the amount

of chemicals that permeated within a specific time.

(1) Gloves were conditioned for a minimum of 24 hours by exposure to room temperature

and a relative humidity (RH) of 52%.

*note: Sodium dichromate ($Na_2Cr_2O_7·2H_2O$) was used to prepare 52% RH at 20°C[20].

(2) The thicknesses of the circular glove pieces of diameter 49 mm were measured with a micrometer (thickness gauge) at three locations within the palm. The diameters exposed to the mixture and collection water solvent were of 24 mm. The specimen weights were determined with an analytical balance.

(3) The specimens were placed between ASTM-type I-PTC-600 permeation cell chambers and the chambers were tightened with a torque wrench. The four assembled cells were placed into a calibrated shaking-tray constant temperature water bath at 35.0±0.5°C.

(4) 10 mL distilled water was charged into each of the four collection sides.

(5) 10 mL of mixtures were put into the challenge sides of three cells and one 10 mL volume of water was inserted into the fourth to provide a method blank. The permeation cells were then shaken at 70±1.2 revolutions/minute at the same time.

(6) A volume of 0.1 mL of sample was removed (100 μL Eppendorf pipet with a long tip) from the collection side of each cell set after the shaker was stopped and stored in a capped 1-mL vial that was parafilmed. Collections were at 0, 5, 10, 20, 30, 45, 60, 80, 100, 120 minutes.

(7) The samples were stored in a 4℃ refrigerator until measurement when the samples were thawed.

(8) The permeated gloves specimens were reconditioned for 24 hours and then measured for the thicknesses and the weights.

2.4. GC-MS Analysis

The samples were analyzed by capillary gas chromatography-selective ion mass spectrometry (GC-MS) by the method of internal standards (4-bromophenol, 4-BP) at a sample concentration of 0.1 μg/μL. The GC column temperature program for the mixture started at 40℃ holding for 6 minutes, ramped at 40℃/min to 90℃, and then directly ramped at 20℃/min to 280℃ with holding for 5 minutes. The temperature program for 2-BE in water and MEA in water started at 120℃ holding for 2 minutes and ramped at 40℃/min, to 280℃ with holding for 4 minutes. The helium carrier flow rate was at 2.0 mL/min.

The injector, link and ion source temperatures were 280℃. The selected ion monitoring mode (SIM) was used to enhance sensitivity and selectivity for the compounds of interest at m/z 43, 57 and 87 for 2-BE, 43 and 61 for MEA, and 172 for 4-BP.

2.5. Data Analysis

The collected data were computerized and statistically analyzed by Microsoft Excel (Office 2016). The *Student* t-test was used to calculate the statistical differences between weights and thicknesses of glove specimen before and after the experiment. Also, the weights and thicknesses were measured three times for each glove specimen to get a precise result. Cumulative mass permeations of chemicals were plotted with amount versus time. The lag time (LT) was measured by extrapolation of the linear steady state section of the permeation curve to the horizontal time axis where mass/area (y-axis) is zero, allowing the calculation of the diffusion coefficient (DC). The standardized breakthrough time (SBT) is the time at which the permeation rate reaches 0.1 μg/cm^2/min. The DC was calculated by extrapolating the mass or mass/area versus time permeation steady state region to zero mass at lag time (D=thickness^2/6*LT).

3. RESULTS

3.1. GC-MS

The retention times for MEA, 2-BE and the internal standards (4-BP) were 8, 13.5 and 18.2 mins, respectively, for the mixture. The total run time for each injection was 21.75 minutes.

The internal standard regressions for 2-BE in water were $y=0.0056x-5.4226$ ($R^2=0.99165$, p=0.004) in the lower level (0, 100, 200, 400, 800, 1000 ng/mL) and $y=0.0029x-3.2576$ ($R^2=0.98757$, p=0.00059) in the upper level (1, 100, 200, 400, 500 ng/μL). The internal standard regressions for MEA in water were $y=0.142x+0.3193$ ($R^2=0.9841$, p=0.0079) in the lower level and $y=6*10^{-5}x+11.52$ ($R^2=0.9686$, p=0.015) in the upper level. The internal standard regressions for 2-BE in the mixture were $y=0.0009x-0.1088$ ($R^2=0.91147$, p=0.0452) in the lower level and $y=0.0023x+41.003$ ($R^2=0.99998$, p=0.0028) in the upper level. The internal standard regression for MEA in the mixture was $y=4*10^{-7}x+0.0157$ ($R^2=0.90111$, p=0.0136).

3.2. Weights and Thicknesses of the Gloves

Tables 1 and 2 show the weights and thicknesses of the gloves. Both weights and thicknesses were measured three times for each glove specimen before and after the experiment. Cells 1-4 were the experiment of the interested mixture (2-BE, MEA, PGNE and water). Cells 5-8 were the experiment of 2-BE in water and cells 9-12 were the experiment of MEA in water.

Table 1 and 2 show the weights and thicknesses of the gloves. Both weights and thicknesses were measured three times for each glove specimen before and after the experiment. Most weights of glove specimen have significant difference; however, thicknesses did not change a lot.

Table 1. Weights of the Glove Specimen before and after the Experiment				
	Before the experiment Mean (g) ± SD	After the experiment Mean (g) ± SD	Student t-test	p-value
Cell 1 (blank)	0.0980±0.0004	0.0960±0.0001	8.4	0.001*
Cell 2	0.0995±0.0004	0.0984±0.0001	3.13	0.035*
Cell 3	0.0993±0.0012	0.1071±0.0001	-11.22	0.0003*
Cell 4	0.0997±0.0012	0.1046±0.00007	-0.71	0.002*
Cell 5 (blank)	0.0954±0.0001	0.0958±0.0002	3.09	0.036*
Cell 6	0.0979±0.0001	0.0979±0.0002	0	1
Cell 7	0.1012±0	0.1012±0.0001	0	1
Cell 8	0.1016±0.0001	0.1016±0	0	1
Cell 9 (blank)	0.017±0.0001	0.1017±0.0001	0	1
Cell 10	0.1015±0.0001	0.1026±0.0001	13.47	0.000176*
Cell 11	0.1032±0.0001	0.1042±0.0001	12.24	0.0003*
Cell 12	0.1015±0.0001	0.1027±0.0001	14.69	0.00013*

*: There was a significant difference of the weights before and after the experiment.

	Before the experiment Mean (mm) ± SD	After the experiment Mean (mm) ± SD	t-test	p-value
Table 2. Thicknesses of the Glove Specimen before and after the Experiment				
Cell 1 (blank)	0.056±0.001	0.058±0.0007	-2.84	0.046*
Cell 2	0.061±0.0017	0.062±0.001	-0.88	0.429
Cell 3	0.061±0.0016	0.061±0.0012	0	1
Cell 4	0.062±0.0007	0.063±0.0007	-1.75	0.155
Cell 5 (blank)	0.059±0.0017	0.062±0.001	1.76	0.153
Cell 6	0.061±0.0006	0.062±0.001	1.49	0.21
Cell 7	0.062±0.0015	0.063±0.0015	0.82	0.458
Cell 8	0.062±0.0006	0.063±0.0012	1.07	0.345
Cell 9 (blank)	0.060±0.0021	0.061±0.0015	0.67	0.54
Cell 10	0.064±0.0026	0.063±0.001	-0.62	0.568
Cell 11	0.064±0.0006	0.065±0.0011	1.29	0.266
Cell 12	0.062±0.0015	0.062±0.001	0	1

*: There was a significant difference of the thicknesses before and after the experiment.

3.3. Permeation

The permeation data and curves are shown in Tables 3-9 and Figures 2-13.

Permeation Time (mins)	Mass (μg)		
	Cell 2	Cell 3	Cell 4
0	5.59	5.52	0
5	368.93	197.60	129.87
10	2326.96	2354.35	2367.19
20	5137.14	5184.44	6931.00
30	9438.38	9045.39	8284.97
45	8764.37	11525.96	9251.09
60	9609.61	12137.24	8986.90
80	12175.59	12896.14	15751.74
100	11558.13	12292.94	13016.49
120	9755.64	8633.72	8304.97

Table 3. Cumulative Permeation of 2-BE in the Mixture through Disposable Nitrile Glove over Time

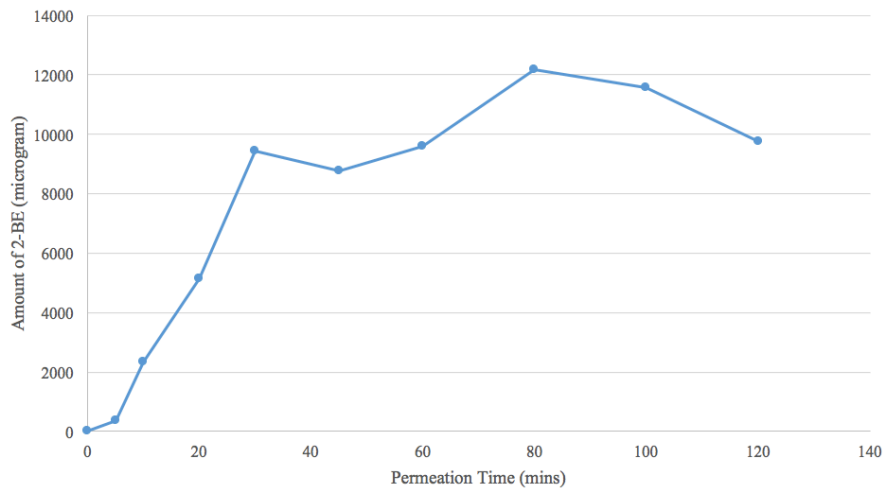Figure 2. Cumulative Permeation of 2-BE in Cell 2
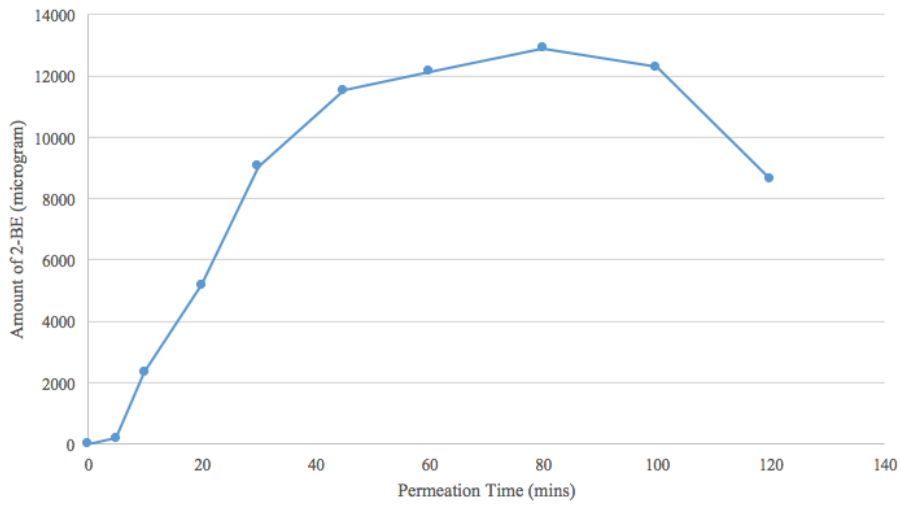

Figure 3. Cumulative Permeation of 2-BE in Cell 3

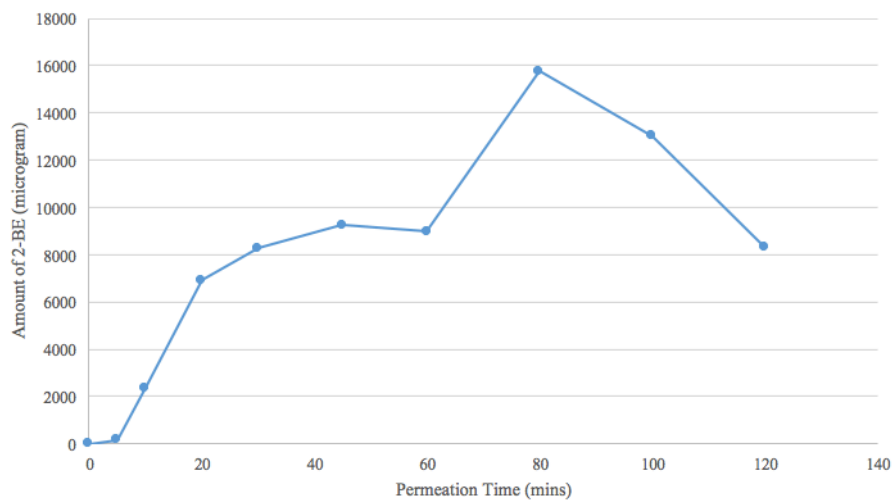Figure 4. Cumulative Permeation of 2-BE in Cell 4

Table 4. Cumulative Permeation of MEA in the Mixture through Disposable Nitrile Glove over Time			
Permeation Time (mins)	Mass (μg)		
	Cell 2	Cell 3	Cell 4
0	0	740.93	0
5	0	7.41	802.66
10	0	7.41	141.41
20	749.69	515.06	401.21
30	5067.57	1296.60	168.06
45	156.34	904.33	15.12
60	61.45	623.91	851.57
80	5825.88	3162.52	5565.84
100	123.43	75.08	83.6
120	123.43	75.08	83.6

Table 5. Permeation Parameters of 2-BE and MEA in the Mixture						
Parameters	2-BE			MEA		
	Cell 2	Cell 3	Cell 4	Cell 2	Cell 3	Cell 4
SSPR (μg/cm^2/min)	78.14	76.06	99.92	56.01	14.25	35.98
Average (μg/cm^2/min)	85$\pm$13			35$\pm$21		
LT (mins)	4.03	4.06	4.69	12.35	10.59	48.49
Average (mins)	4.26$\pm$0.37			23$\pm$21		
SBT (mins)	0-5	0-5	0-5	5-10	5-10	5-10
Average (mins)	0-5			5-10		
DC (cm^2/min)	$1.54*10^{-4}$	$1.53*10^{-4}$	$1.37*10^{-4}$	$5.02*10^{-5}$	$5.86*10^{-5}$	$1.32*10^{-5}$
Average (cm^2/min)	$(14.8\pm1.0)*10^{-5}$			$(4.1\pm2.4)*10^{-5}$		

*SSPR (Steady-state permeation rate): The constant rate of permeation that occurs after breakthrough when the chemical contact is continuous and all forces affecting permeation have reached equilibrium.

*LT (Lag time): Measured by extrapolation of the linear steady state section of the permeation curve to the horizontal time axis where mass/area (y-axis) is zero, allowed the calculation of the diffusion coefficient.

*SBT (Standardized breakthrough time): The time at which the permeation rate reaches 0.1 μg/cm^2/min.

*DC (Diffusion coefficient): Diffusion of chemicals through the material of the glove, can be calculated by extrapolating the mass or mass/area versus time permeation steady state region to zero mass at lag time. D=thickness^2/6*LT
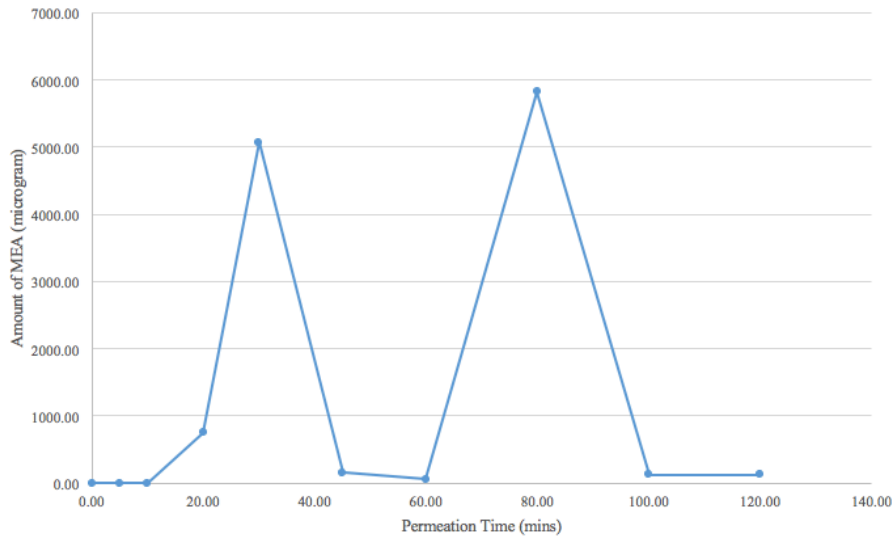
Figure 5. Cumulative Permeation of MEA in Cell 2

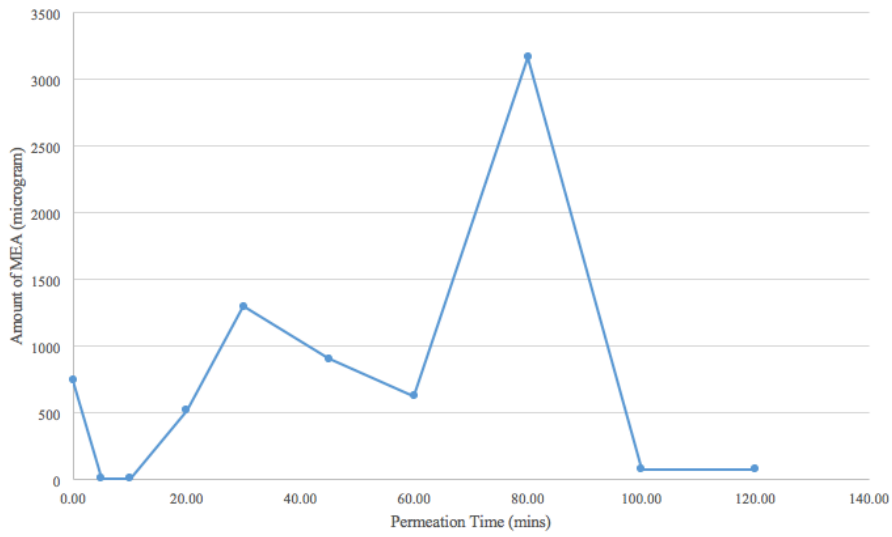Figure 6. Cumulative Permeation of MEA in Cell 3
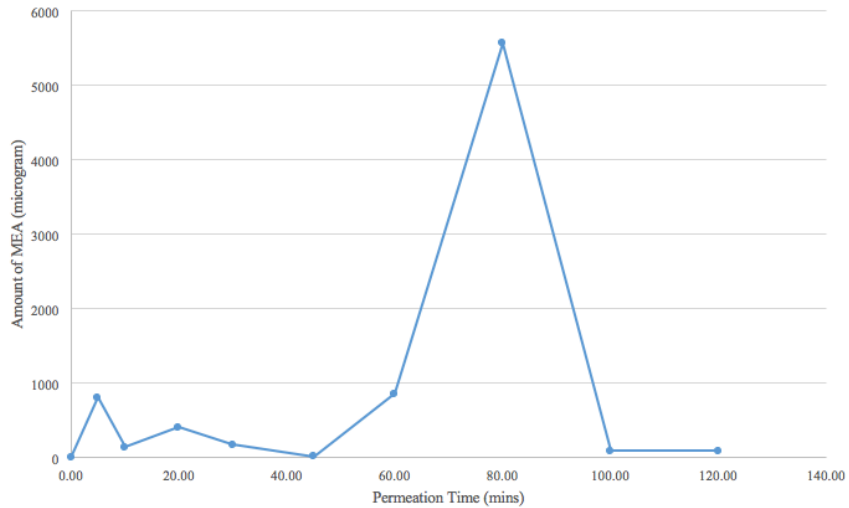

Figure 7. Cumulative Permeation of MEA in Cell 4

Table 6. Cumulative Permeation of 2-BE in Water through Disposable Nitrile Glove over Time

Permeation Time (mins)	Mass (μg)		
	Cell 6	Cell 7	Cell 8
0	0	0	0
5	0	0	0
10	621.51	475.54	844.29
20	3494.58	4071.88	5337.75
30	8533.85	9679.05	12727.54
45	15550.64	19995.32	22642.46
60	29450.54	34908.43	43648.08
80	69127.56	58276.36	70821.89
100	56348.57	68922.79	91561.26
120	72586.43	73365.60	88247.95

Table 7. Permeation Parameters of 2-BE in Water

	Cell 6	Cell 7	Cell 8
SSPR (μg/cm^2/min)	284.64	242.66	278.65
Average (μg/cm^2/min)	269$\pm$23		
LT (mins)	34.45	27.30	25.90
Average (mins)	29.2$\pm$4.6		
SBT (mins)	5-10	5-10	5-10
Average (mins)	5-10		
DC (cm^2/min)	$1.8*10^{-5}$	$2.3*10^{-5}$	$2.5*10^{-5}$
Average (cm^2/min)	$(22\pm3.6)*10^{-6}$		

*SSPR (Steady-state permeation rate); LT (Lag time); SBT (Standardized breakthrough time); DC (Diffusion coefficient).
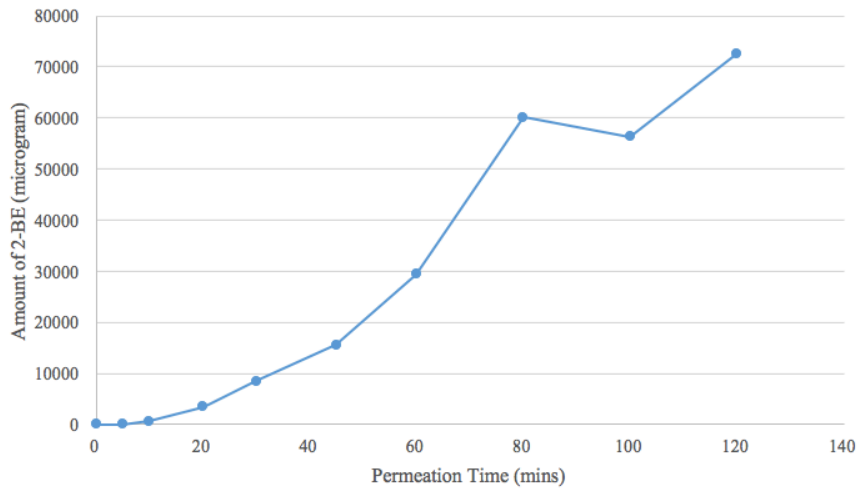
Figure 8. Cumulative Permeation of 2-BE in Cell 6

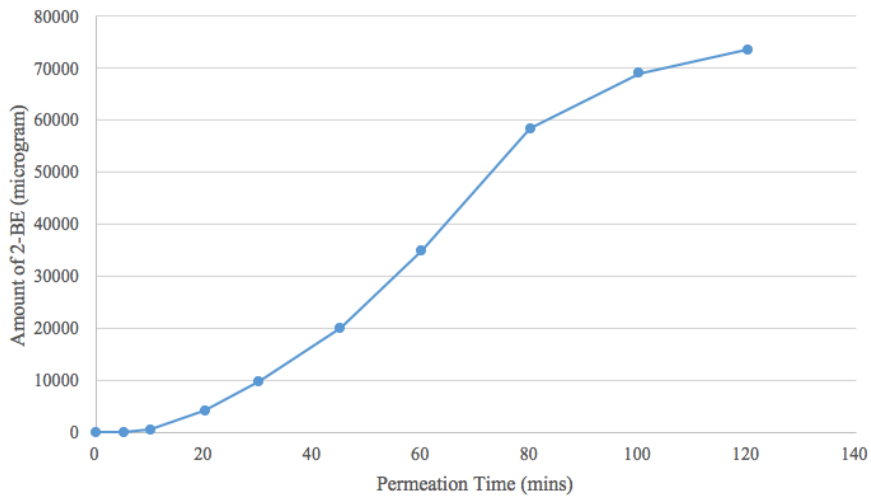Figure 9. Cumulative Permeation of 2-BE in Cell 7

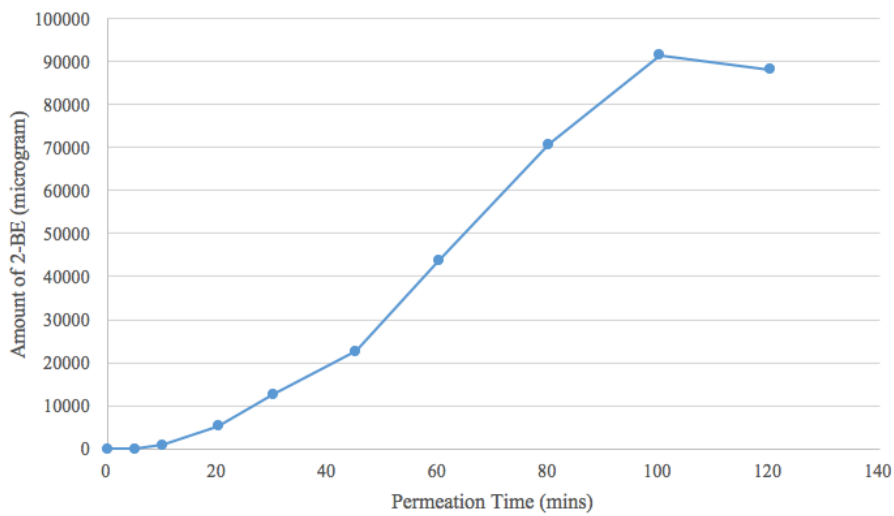Figure 10. Cumulative Permeation of 2-BE in Cell 8

Table 8. Cumulative Permeation of MEA in Water through Disposable Nitrile Glove over Time			
Permeation Time (mins)	Mass (μg)		
	Cell 10	Cell 11	Cell 12
0	0.06	0.02	0.30
5	5.13	5.66	7.13
10	12.05	8.13	12.35
20	1527.92	1398.56	2021.03
30	2916.72	2134.54	2641.83
45	5481.72	4801.04	5673.92
60	7942.96	7744.81	8268.32
80	9448.01	9226.61	9469.57
100	9917.21	9674.34	9955.63
120	9187.69	9295.17	10066.35

Table 9. Permeation Parameters of MEA in Water			
	Cell 10	Cell 11	Cell 12
SSPR (μg/cm^2/min)	35.16	36.01	41.45
Average (μg/cm^2/min)	37.5$\pm$3.4		
LT (mins)	10.52	14.07	15.52
Average (mins)	13.4$\pm$2.6		
SBT (mins)	10-20	10-20	10-20
Average (mins)	10-20		
DC (cm^2/min)	6.39*10^{-5}	4.93*10^{-5}	4.13*10^{-5}
Average (cm^2/min)	(5.2$\pm$1.2)*10^{-5}		

*SSPR (Steady-state permeation rate); LT (Lag time); SBT (Standardized breakthrough time); DC (Diffusion coefficient).
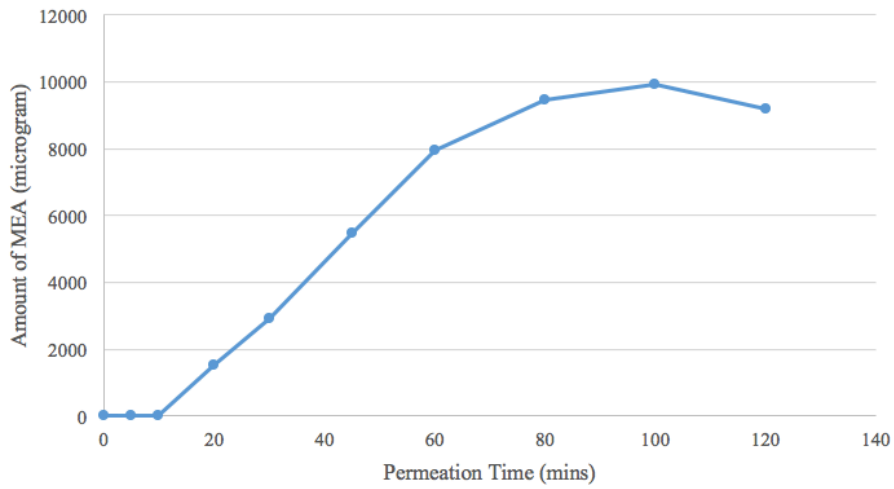
Figure 11. Cumulative Permeation of MEA in Cell 10

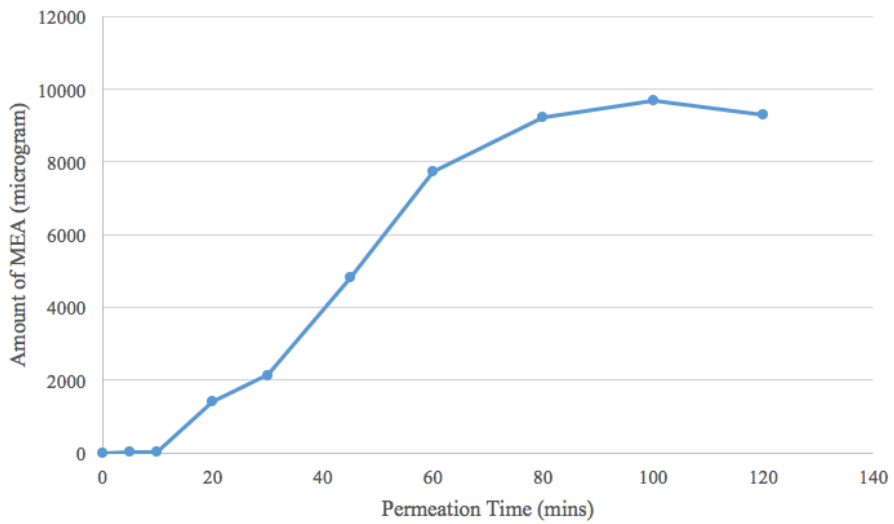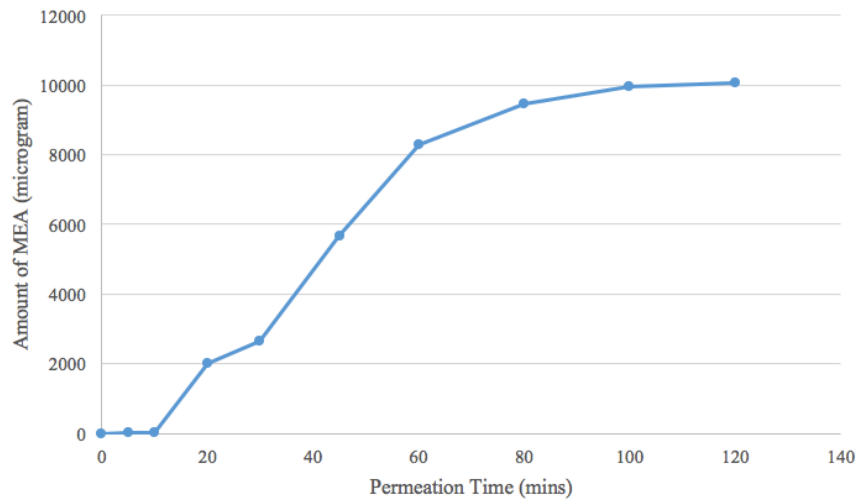Figure 12. Cumulative Permeation of MEA in Cell 11

Figure 13. Cumulative Permeation of MEA in Cell 12

4. DISCUSSION AND CONCLUSIONS

According to the Kimberly-Clark Nitrile Gloves-Chemical Resistance Guide[4], if the permeation breakthrough time is less than 1 minutes, the glove is not recommended; 1-9 minutes, the rating is poor; 10-59 minutes as good and 60-480 minutes as excellent. The standardized breakthrough times (SBTs) of 2-BE in the mixture were 0-5 min, the SBTs of MEA in mixture were 5-10 min, the SBTs of 2-BE in water were 5-10 min and the SBTs of MEA in water were 10-20 min. Thus, this disposable nitrile glove is not recommended to resist 2-BE in the mixture. The rating is also poor for MEA in the mixture, 2-BE in water and MEA in water.

The hypothesis of this study was that some chemicals in the mixture will permeate through the disposable nitrile glove faster in the presence of other chemicals. The SBTs of 2-BE and MEA in the mixture were faster than those in water in the results. It indicated that 2-BE and MEA in the mixture can permeate through glove materials faster than expected from in the solvent alone, which is consistent with the previous studies[2,3].

The steady-state permeation rates (SSPRs) of 2-BE and MEA in the mixture were 85±13 and 35±21 $\mu g/cm^2/min$, respectively. The SSPR of 2-BE in water was 269±23 $\mu g/cm^2/min$ and the SSPR of MEA in water was 37.5±3.4 $\mu g/cm^2/min$. While the SSPR of MEA did not

differ statistically at p ≤0.05, that for 2-BE in the mixture decreased by about one-third, indicative of an antagonistic effect relative to in water alone. The mechanism of the effect needs to be investigated further.

The permeation behavior of 2-BE in the mixture is close to type B, which is due to the material specimen being structurally modified by the chemical resulting in an increase or decrease in permeation rate[1]. The permeation behavior of 2-BE in water is type A, the most typical, where the permeation rate stabilizes at a "steady state" value. The permeation behavior of 2-BE in water is the same in Song's study[21]. For MEA in the mixture, the permeation behavior could not be evaluated because the amount of MEA permeated through the glove specimen varied over time. The permeation behavior of MEA in water is A but the curve went down slightly at 120 minutes. Figure 14 provides the 5 types of permeation behavior[1].
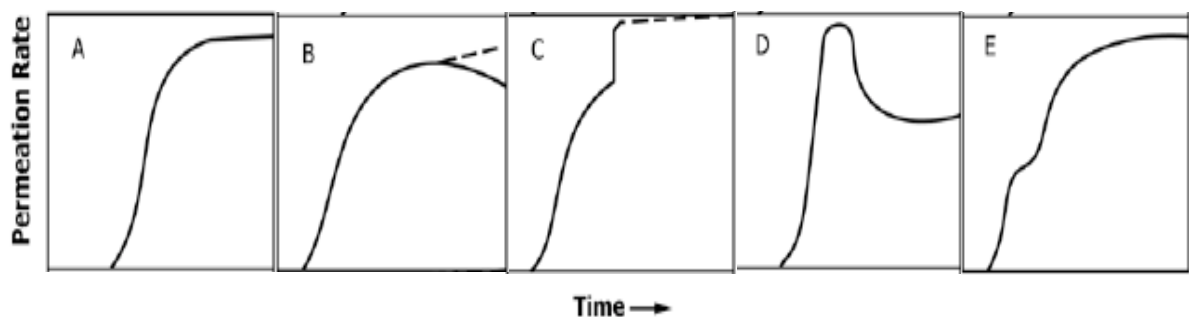

Figure 14. Five Types of Permeation Behavior

PGNE is a polymer, with the molecular weight of 680.0 g/mole. The mass can be detected in this study was 40-550. Thus, PGNE could not be detected by GC-MS, and it is difficult to evaluate the effect of PGNE on permeation. In addition, our attempt to investigate the actual commercial mixture failed because the actual product could not be ordered in a small amount. It made the evaluation of mixture more challenging if there is any secret compound in it. Another limitation is that the ASTM F739-12 does not simulate hand motions, so the influence of hand motions could not be evaluated in this study.

The present study can help advance the knowledge of glove permeation of mixtures through disposable nitrile gloves. Since the permeation will occur faster if the glove is exposed to the studied mixture, workers exposed to mixtures should reduce the time using the same gloves and increase the frequency of changing new gloves to protect themselves. Further studies should be done to investigate the effects of different mixtures on glove permeation.

5. REFERENCES

(1) American Society for Testing and Materials (ASTM), *Method F739-12, Standard Test Method for Permeation of Liquids and Gases through Protective Clothing Materials under Conditions of Continuous Contact*, 2012.

(2) Keh-Ping Chao, Ya-Ping Hsua and Su-Yi Chena, *Permeation of Aromatic Solvent Mixtures through Nitrile Protective Gloves*, Journal of Hazardous Materials, 153, 1059–1066, 2008.

(3) Yu-Wen Lin and Shane S. Que Hee, *Permeation of a Malathion Formulation through Butyl Gloves*, Journal of Hazardous Materials, 60, 143-158, 1998.

(4) Kimberly-Clark®, *Nitrile Gloves Chemical Resistance Guide,* 2010.

(5) J. Crank, *The Mathematics of Diffusion,* Oxford University Press Inc., New York, 1975.

(6) Hsiao-Shu Lee, Yu-Wen Lin, P*ermeation of Hair Dye Ingredients, p-Phenylenediamine and Aminophenol Isomers, through Protective Gloves*, The Annals of Occupational Hygiene, Vol. 53, Issue 3, p. 289–296, 2009.

(7) U.S. National Library of Medicine, PubChem, *2-Butoxyethanol, Compound Summary for CID 8133,* 2012.

(8) Sigma-Aldrich, *Ethylene glycol butyl ether-Safety Data Sheet,* 2016.

(9) The Occupational Safety and Health Administration (OSHA), *Hazard Communication*, https://www.osha.gov/dsg/hazcom/

(10) American Conference of Governmental Industrial Hygienists (ACGIH), *TLVs® and BEIs®*, 2018.

(11) U.S. National Archives and Records Administration's Electronic Code of Federal Regulations (29 CFR 1910.1000), 2011.

(12) Lewis, R.J. Sr., *Sax's Dangerous Properties of Industrial Materials*, 11th ed. Wiley-Interscience, Wiley & Sons, Inc. Hoboken, NJ., p. 595, 2004.

(13) Sigma-Aldrich, *Ethanolamine-Safety Data Sheet*, 2017.

(14) Knaak JB, Leung H-W, Stott WT, Busch J, Bilsky J, *Review of Environmental Contamination Toxicology*, 149: 1-86, 1997.

(15) Christian M, ed; J American College of Toxicology 2 (7): 183-226, 1983.

(16) Bingham, E., Cohrssen, B., Powell, C.H., *Patty's Toxicology*, Volumes 1-9, 5th ed. John Wiley & Sons. New York, N.Y., p. V4 782, 2001.

(17) United States Environmental Protection Agency (EPA), *Prevention, Pesticides and Toxic Substances; Status of Pesticides in Registration, Reregistration, and Special Review*, EPA 738-R-98-002 p.272, 1998.

(18) Sigma-Aldrich, *Nonidet$^®$ P 40 Substitute-Safety Data Sheet*, 2017.

(19) FullPro, *Vanquish No Rinse Stripper‑Safety Data Sheet*, 2014.

(20) Maryadele J. O'Neil, Patricia E. Heckelman, Cherie B. Koch, Kristin J. Roman, Catherine M. Kenny, Maryann R. D'Arecca, *The Merck Index*, 1989.

(21) Eun Jin Song, *Comparison of Permeation of 2-Butoxyethanol Through Single and Multiple Layers of Disposable Nitrile Gloves*, Master's thesis, UCLA, 2017.